CHAPTER 6

Recommendations and Conclusions

6.1 WACAP Recommendations to NPS

6.1.1 Introduction

These recommendations are related to the original five WACAP objectives and have been specifically requested by the NPS as a product of this project. They are based on the results of WACAP (as well as other relevant scientific literature, in some cases).

The WACAP objectives were to determine:

1. If contaminants are present in western national parks
2. Where contaminants are accumulating (geographically and by elevation)
3. Which contaminants pose a potential ecological threat
4. Which indicators appear to be the most useful to address contamination
5. What the sources were for contaminants measured at the national park sites

Recommendations stem from the question posed by NPS, “What did you learn in this project that could help guide or focus future work within the NPS on contaminants in western U.S. parks?”

6.1.2 Presence of Key Contaminants

- Dieldrin, DDT, chlordane, and mercury were found to be key compounds/elements that are atmospherically deposited within WACAP parks because they have a combination of higher concentrations and greater toxicity in the food web than other analytes.

  Therefore NPS could consider focusing on dieldrin, DDTs, chlordane, and mercury in future work when assessing highest risk to western park resources is desired. Since spectral analytical techniques for the semi-volatile organic compounds (SOCs) often result in identification of multiple compounds, the benefits of looking at additional compounds at minimal extra cost should be considered.

- Mercury concentrations in fish tissue routinely exceeded piscivorous animal thresholds, and in some parks, human contaminant health thresholds were also exceeded.

  Therefore, assessing mercury concentrations and impacts on fish could be considered a high priority for future analysis in parks. As evidence is emerging concerning the important role of selenium in binding with methyl mercury in organisms, and possibly reducing the toxic effects of mercury in the environment, future work on mercury should consider also measuring and evaluating selenium.

- Deposition of HUPs (historic-use pesticides) was shown to be decreasing fairly consistently, while deposition of CUPs (current-use pesticides) is increasing in many parks.

  Therefore, NPS could consider focusing on current-use pesticides and other current-use chemicals.

- Sediment records show that deposition of some current-use SOCs and PBDEs is increasing over time in some areas: McLeod Lake (DENA) shows increasing endosulfans; Matcharak Lake (GAAR) shows increasing PAHs; Oldman and Snyder lakes (GLAC) show increasing dacthal and endosulfans; PJ Lake (OLYM) shows increasing dacthal and endosulfans; LP19 and Golden Lake (MORA) show increasing endosulfans; Lone Pine Lake (ROMO) shows increasing endosulfans and Mills Lake (ROMO) shows increasing endosulfans and PBDEs.

  Because increased use and deposition of these SOCs has been documented, the deposition and potential health effects (on wildlife and humans) of these current-use pesticides could continue to be assessed over time, particularly in parks near agricultural sources (such as SEKI, ROMO, and GLAC). The most effective approach for tracking the changes in deposition in these compounds over time and the thresholds for their impacts to human and wildlife health, would need to be determined.

6.1.3 Locations of Contaminant Accumulation

- Contaminants were found in all WACAP lakes; in some cases, the concentrations in fish were found to exceed important human and wildlife thresholds. It might be perceived that the two lakes per park that WACAP examined are somehow outliers and that they do not represent the total population of lakes within parks. From a strictly statistical perspective, these lakes are not representative of the population of lakes. However, the lakes were selected to provide "clean," unambiguous signals of atmospherically deposited contaminants and in no way were they selected to provide the highest or lowest contaminant concentrations.

  Researchers conducting future work might choose to consider implementing a robust statistical sampling design for specific parks that would provide a quantitative estimate of the contaminant condition of all lakes in the population.

- SOC and nitrogen concentrations in WACAP parks were shown to be closely associated with proximity to regional sources (agricultural, point, and urban sources).

  Therefore NPS could consider monitoring SOC and nitrogen concentrations in areas closest to these source types, where identification of "hot spots" of contaminants is desired.

- Of the SOCs detected in air and vegetation throughout the 20 core and secondary WACAP parks, endosulfans and dacthal were the dominant current-use pesticides, and HCB and a-HCH were the dominant historic-use pesticides. In general, GLAC and SEKI, followed by YOSE and GRSA, had the highest concentrations of SOCs among the WACAP parks; air and vegetation concentrations of CUPs were lowest in Alaska parks; concentrations of HUPs did not differ among the parks. These findings imply risk to terrestrial ecosystems, but accumulation in aquatic ecosystems is unknown.

  Therefore monitoring of SOCs in vegetation and other indicators (snow, fish, sediment) might be fruitful in additional parks in California and the Rocky Mountains.

- GRSA contains very high concentrations in lichens (compared with most other parks) of dacthal, endosulfans, HCB, a-HCH, g-HCH, chlordanes, and DDT.

  Further investigation of the sources and extent of these contaminants in GRSA ecosystems might be desirable.

- Industrial and agricultural contaminants were abundant in ROMO ecosystems. Fish gonadal abnormalities (feminization of males and abnormalities in immature females) were observed in the park, and some of these fish had high contaminant burdens. The relationship between the two results is statistically significant, but complicated because of the small sample sizes.

  The NPS might wish to conduct future studies regarding causes of fish abnormalities, including evaluation of potential interactions of multiple contaminants.

- Pacific Coast parks contain a combination of high contaminant concentrations in needles and dense forest foliage.

Therefore, NPS might wish to assess whether this combination could result in high loading of contaminants to the ecosystem from canopy leachates and forest litter fall in these parks.

- High concentrations of some contaminants in a single snow sample in DENA (2,500-m elevation), along with greater precipitation amounts at higher elevations, suggests potential for greater contaminant loading and higher ecological effects at high elevations in this park.

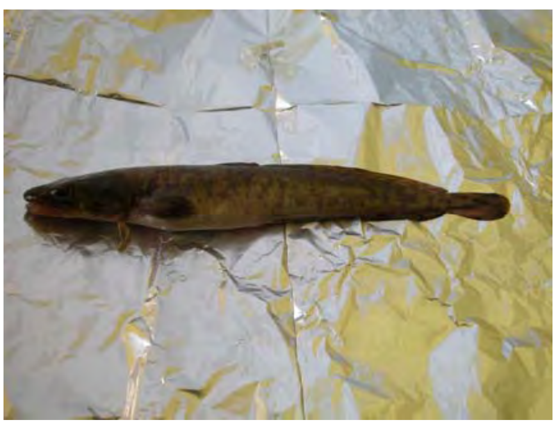
  WACAP suggests further exploration of contaminants at elevational gradients in this park.

6.1.4 Ecological Threat From Contaminants

- Fish are a key indicator in parks because, as shown in this study and others, bioaccumulation of contaminants in their tissues puts them at risk for adverse effects, as well as the species that eat them (birds, wildlife, humans).

  Therefore, NPS might wish to give first priority in bioaccumulation studies to assessing contaminant concentrations in fish, to determine current risk to fish and consumers of fish, before investigating other food web indicators.

- Fish were chosen as the primary indicator of ecosystem health in WACAP. However, other studies have shown that each ecosystem food web varies in how it accumulates contaminants.



  Therefore, although fish are recommended as a key indicator for initial assessment of contaminant impacts, when fish contamination concentrations conflict with other measurements, fish concentrations might not reflect all parts of the food web. In these cases, assessing food web structure and ecosystem processing variables may help determine whether further bioaccumulation assessments might be needed in other indicators (e.g., song birds, insects, amphibians, mammals).

- Contaminant concentrations were generally correlated with fish age and lipid (in this and other studies), because fish tend to accumulate more contaminants in tissues as they eat and grow older.

  Therefore, determining the ages and lipid of fish assessed for contaminants in future studies could help provide comparability among data sets or aid in the understanding of variability among fish.

- Concentrations of mercury in fish were not always directly related to levels in atmospheric deposition and flux (e.g., in some Alaska sites, mercury deposition was low, but concentrations in fish were high). Bioaccumulation and biomagnification of mercury is controlled largely by methylation processes and food web structure.

Therefore future studies should consider these factors in study designs, when assessment of areas of highest risk is desired.

- Some lakes in GLAC and ROMO contain reproductively abnormal male fish, evidenced by the presence of eggs and sperm in the same fish, testicular abnormalities, elevated levels of female-specific protein in the blood, and elevated SOC concentrations in these fish.

  Further research in other lakes in these parks as well as other parks in the Rocky Mountains (GRTE, GRSA) could be conducted to assess the spatial extent of these conditions, associated fish SOC concentrations, and the potential impact on fish populations in these parks.

- There is strong inferential evidence that the intersex condition and female-specific protein (Vtg) found in some fish in the study can be explained by endocrine disruption related to contaminants.

  There is a chance that further investigation could find this contention to be wrong, but the "precautionary principle" argues for continuing to explore these potential linkages between fish condition and contaminants in western parks.

- Other studies have shown that fish accumulated greater amounts of some SOCs in livers than in fillets.

  Because NPS is concerned about effects of bioaccumulation on fish, birds, and wildlife, analysis of whole fish in parks (rather than fillets alone) is suggested to enable comparison of results with fish and wildlife toxicity thresholds. Conversions of concentrations from whole fish to fillet values can subsequently be made to estimate risk to humans.

- Willow bark was evaluated in this study to assess accumulation of contaminants in vegetation that could be browsed by animals. It was difficult, however, to identify the willow species in the field, and willow bark was more difficult to analyze for SOCs in the lab.

  Therefore willow bark is not currently recommended as a useful ecosystem indicator in NPS future studies.

- Select PBDE concentrations were fairly high in WACAP fish (higher than in Pacific Ocean salmon) and increasing in some sediments. In addition, human and wildlife contaminant health thresholds for select PBDEs have not yet been adopted, but are more accurate than the current threshold.

  Therefore in future studies, NPS might wish to measure select PDBEs in fish to determine if there is a temporal trend in concentrations or risk.

6.1.5 Sources of Contaminants

- This study identified several parks in which individual contaminants or suites of contaminants suggest current local or regional source contributions.

  NPS might wish to further investigate recent local source contributions of: (1) PAHs at GLAC, (2) current-use SOCs at ROMO, GLAC, and SEKI, and (3) PBDEs at ROMO and MORA.

- Sediment records showed steadily increasing mercury deposition over time at lakes in two parks (MORA and ROMO). Because these patterns differ from those at other western parks, the sources of mercury could be local rather than global.

  NPS could consider additional work to determine the extent to which local sources contribute to mercury deposition at these parks.

- Long-range, global (including trans-Pacific) SOC and mercury sources contribute a greater percentage of the total SOC deposition in OLYM, DENA, and NOAT than do regional North American sources.

  NPS might wish to continue monitoring the deposition of SOCs and mercury in these parks to better track the relative contribution of global sources over time.

6.1.6 Understanding Contaminant Processes in Ecosystems

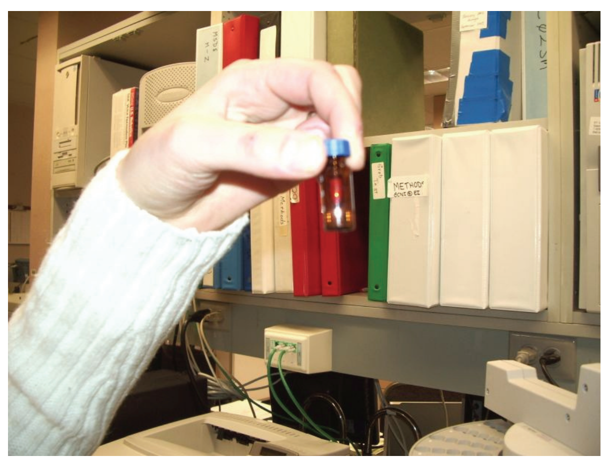
This project has helped to elucidate some of the questions that will have to be addressed in the future for a better understanding of how contaminants move into and through park ecosystems. Understanding these processes, mechanisms, and ecosystem interactions will be important in advancing contaminants research in the United States. However, because many of these types of questions are beyond the scope of the key WACAP objectives, they have not been developed as specific recommendations to NPS. However, several of the questions that have been identified by WACAP investigators are included here as potential areas of interest for future research:

- Which ecosystem variables are the best predictors of contaminants risk to lake catchments?
- How important are various deposition processes, including rain, snow, fog, rime ice, and dry deposition, in delivering contaminants to ecosystems?
- What is the fate (mass balance/budget) of SOCs in deposition? How much is re-volatilized to the atmospheric from vegetation, soil, or water? How much accumulates in terrestrial or aquatic ecosystems? How much is transported to downstream environments in stream flow?
- How can SOC concentrations be used to predict other contaminants?
- Can information about the half-lives of contaminants found in parks be used to predict future trends for increases or decreases in these ecosystems?
- What is the effect of interaction among multiple contaminants in ecosystems?
- What are the ecosystem variables in Alaska parks that result in higher bioaccumulation of mercury in fish there?
- What will be the synergistic impacts on bioaccumulation of contaminants with global change, regional land-use change, wildfire, and other regional-scale anthropogenic changes?

- What are the impacts of contaminants in parks on other parts of the food web not studied in the project (e.g., mink, piscivorous birds, amphibians)?
- What are the speciated components of mercury in the air, and what do the proportions of reactive gaseous mercury and particulate mercury tell us about regional mercury source contributions?
- How do the types and locations of vegetation selected for sampling influence contaminant uptake (e.g., vegetation under snowpack compared with vegetation exposed year round).
- What is the extent of the cold fractionation effect of SOCs in vegetation accumulating preferentially at high elevations in some parks?
- How should contaminants be tracked over time in parks where they have been identified as potentially increasing (in sediments, snow, air, vegetation, and fish)?
- What are thresholds of concern for the effects of bioaccumulation of emerging contaminants (e.g., PBDEs) on fish, wildlife, and humans?
- Over what timeframe do various contaminants degrade in sediments? Do concentrations of contaminants change over time once they have been deposited?

6.2 Conclusions

The transport, fate, and ecological effects of anthropogenic contaminants from atmospheric sources were assessed in air, water, snow, sediment, vegetation, and fish in eight core national parks in the western United States. In addition, air and vegetation were sampled in twelve secondary national parks, preserves, and national forests in the western United States to further enhance spatial interpretations of the data. Samples were analyzed for SOCs (CUPs and HUPs, industrial compounds, and PAH), mercury, and other metals. Relative to the WACAP objectives, major conclusions are as follows.



Out of more than 100 SOCs tested (excluding PBDEs in fish and sediments), 70 were found at detectable concentrations in air, snow, water, vegetation, sediment, and/or fish. Six contaminants of highest concern were identified for the eight core park ecosystems studied: mercury, dieldrin, DDT, PCBs, chlordane, and PAH. These contaminants are of highest concern because of (1) the high concentrations detected, (2) the bioaccumulation documented, and/or (3) their toxic or persistent characteristics in the environment. Other contaminants identified as potential concerns are PDBEs, endosulfans, dacthal, chlorpyrifos, HCB, a-HCH, and g-HCH, because they are (1) in current use, (2) are present at comparatively high concentrations in vegetation or fish, and/or (3) are increasing over time in sediment cores.

Contaminants were shown to accumulate geographically based on proximity to individual sources or source areas. Pesticide concentrations for both HUPs and CUPs were highest in parks and park watersheds closest to agricultural areas. Concentrations of industrial contaminants (PAHs and mercury) were sometimes elevated near parks where local/regional sources produce these contaminants. This finding is counter to the original working hypothesis that most of the contaminants found in western parks would originate from eastern Europe and Asia and travel across the Pacific to the western United States. There was evidence that this phenomenon does occur, but contaminant contributions from trans-Pacific sources of SOCs were small compared to other regional sources closer to the parks. Regarding mercury, in particular, deposition is composed of a complex mixture of local, regional, and global sources.

Contaminants were found to bioaccumulate in ecosystems (higher concentrations in older vegetation than in younger vegetation), and biomagnify at higher levels of the food web (concentrations in fish higher than those in air, snow, or water). Bioaccumulation and biomagnification of contaminants in ecosystems have been shown in other studies to occur elsewhere, but not at these regional scales in remote ecosystems in the western United States.

Among the contaminants found in western park ecosystems, mercury and dieldrin are likely to pose the greatest ecological threat. Mercury is a common component of coal. On a global scale, approximately two-thirds of the anthropogenic mercury emitted is from the combustion of fossil fuels. When mercury is deposited in the environment and biologically converted to its toxic form (methyl mercury), it can bioaccumulate readily in food chains and cause neurological and other detrimental effects in humans, fish, and other organisms. Although mercury deposition in Alaska parks was low, in-lake biological processes specific to the lakes in these parks contributed to concentrations in fish that exceeded contaminant health thresholds for humans and wildlife. The average mercury concentration in fish from Burial Lake (NOAT) exceeded the human contaminant health threshold. Average mercury concentrations in fish at GAAR and DENA (Wonder Lake) fell between the human and otter contaminant health thresholds, and mercury concentrations in all fish from the four Alaska lakes, except for one fish from McLeod Lake (DENA), were above the contaminant health thresholds for kingfisher (see Figure 5-18). Mercury concentration thresholds for risk to birds and wildlife were routinely exceeded at most lakes in most parks. Dieldrin is an acutely toxic insecticide, categorized as a carcinogen and a known endocrine-disrupting compound. It was banned from use in the United States in 1987 and in Canada in 1990. However, concentrations of dieldrin found in fish in some parks in this study were still high, and in some cases exceeded USEPA contaminant health thresholds for increased cancer risk to humans, but not the thresholds for risk to birds and wildlife. It is not currently known why concentrations remain high in parks near agricultural areas two decades after the product was banned, but dieldrin is known to be persistent in the environment.

The ecological indicators found to be most useful in interpreting contamination in this study were fish, sediments, conifer needles, and lichens. Fish were important as an indicator of bioaccumulation of contaminants and potential impacts to food webs. Sediments provided a historical context, documenting changes in contaminants over time, and retaining clues about contaminant sources through historical deposition of metals and SCPs (spheroidal carbonaceous particles). Second-year conifer needles proved to be an effective current measure of several types of contaminant concentrations over large spatial scales. Because their age is known and their biomass is large, conifer needles provided an ecologically relevant measure of yearly contaminant loading in vegetation. Lichens, with a higher capacity for SOC accumulation, and with occurrence in both forested and arctic-alpine ecosystems, indicate differences in SOC concentrations along elevational gradients and among sites within parks. However, lichens cannot be aged, and therefore, the period of time over which contaminants are accumulated in lichens is unknown, complicating their interpretation. Consistently sampling a single species and collecting samples above or below winter snow lines improves the sensitivity of vegetation indicators.

The sources of contaminants in western national parks vary by region. In Alaska, there are few local or regional sources of contaminants, and deposition of contaminants is influenced primarily by transport from other source regions. In general, deposition of CUPs and HUPs is most strongly influenced by proximity to agricultural and industrial areas. An aluminum smelter near GLAC contributes to high concentrations of PAHs in snowpack, sediment, and lichens at Snyder Lake.

The knowledge gained from this project should add considerably to the state of the science about contaminant transport, flux, and biological and ecological effects in remote ecosystems in the western United States. However, it also serves to raise many additional questions. Related work, if conducted in the future, might explore some of these areas, identifying the various temporal and spatial dimensions of contaminant pathways and defining and documenting the extent and magnitude of specific ecological effects.